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DD MIXTURE AS A SOIL FUMIGANT

By S. B. Fracker, G. Steiner, H. P. Barss, and F. C. Bishopp,
a special committee, Agricultural Research Administration,
U. S. Department of Agriculture

Introduction

About August 1, 1943, Dr. Albert L. Elder, Chemical Division, War Production Board, asked the Agricultural Research Administration to make such preliminary tests as would provide a basis for an estimate of the potential agricultural usefulness of a product of the Shell Company known as DD mixture, proposed as a new soil fumigant.

The Agricultural Research Administration set up the committee which has prepared this report, to plan, coordinate and interpret such tests. The experiments were carried out in widely separated parts of the country in order to provide a diversity of soils and pests.

DD mixture, the material tested, is a mixture of 1, 3-dichloropropylene and 1, 2-dichloropropane obtained as a byproduct in the manufacture of allyl alcohol from petroleum. Its usefulness as a soil fumigant was first announced by Dr. Walter Carter (Science, Apr. 23, 1943) as a result of several years trials at the Pineapple Research Institute in the Hawaiian Islands.

The composition of the mixture as made available to experimenters has varied to some extent. According to information received from Mr. L. V. Steck of the Shell Development Company, practically all of the material provided for the tests reported here contains about 30 to 33 percent low boiling and 30 to 33 percent high boiling, 1,3-dichloropropylene, about 30 to 35 percent 1, 2-dichloropropane and about 5 percent heavy trichlorides of propane. These proportions thus differ somewhat from those of the material reported on by Dr. Carter. A number of the experimenters, as indicated in the report, added an emulsifying agent (4%) to make the material miscible with water. In a few instances the material was distilled to get rid of the heavy trichlorides, but this did not seem to change the effectiveness materially.

The committee in this report has used the term "crude DD" or "straight DD mixture" for the material from which the 5% heavy trichlorides had not been eliminated, and "DD emulsion" for the undiluted material with an emulsifying agent. In a few cases reference is also made to "distilled DD".

The company reports that the mixture has the following characteristics:

Density 1.198

Pounds per gal. 10

Flash point, Tag open cup 80°F.

Distillation ASTM D- 68-41)

Initial	93G
Dry	155
5%	101
50%	108
95%	142

Vapor pressure

0°C	10.1
20°C	31.3
30°C	51.6
40°C	82.1

The structural formula of 1, 3-dichloropropylene is given as CHCl = CH - CH2Cl, and its solubility as 1.97 gm. of the low-boiling isomer to the liter of water at 20°C. The high-boiling isomer has a solubility of 2.17.

The formula of 1, 2-dichloropropane is $CH_2Cl-CHCl-CH_3$, with a solubility of 2.80 gm per liter.

One cc per square foot is equivalent to a dosage of 115 pounds per acre. Such an application would cost $17.25 per acre if the material should be priced at 15¢ per pound. Ten cc applied at 1½ foot intervals equals 510 pounds per acre and would cost $76.50 at that price.

Since nothing was known, prior to Carter's work, of the biological properties of this mixture, preliminary tests have been made on a wide variety of organisms. Their results are reported on later pages, grouped in five sections:

A. Effect on nematodes
B. Effect on fungi
C. Effect on insects
D. Effect on miscellaneous organisms
E. Precautions to be observed

Summary

The effect on each group of organisms is summarized at the end of the applicable section. For convenience these summaries are repeated here.

Conclusions as to the usefulness of the D-D mixture as a Soil Fumigant for Nematode Control

1. The D-D mixture, either in crude, purified, or emulsified form, properly injected or applied, proved highly effective in control of the root-knot and the meadow nematode in sandy loam, and silt loam soils of rather low moisture and low organic content.

2. The D-D mixture proved only about 35 to 40% effective in control of the root-knot nematode in Everglades peat of high moisture (around 65%) and high organic (85 to 87%) content.

3. Soil moisture content above a certain level tended to retain D-D ingredients toxic to plant growth without increasing the lethal effect on nematodes.

4. In these preliminary tests it was not possible to carry the plants through to maturity so late in the season, and to obtain final yield records. The field test at Beltsville showed, however, during a growth period of six weeks, a marked increase (125 percent) in plant growth on treated as compared with untreated soil. While Dr. Carter reports a similar favorable effect on growth, and this effect tends to be confirmed by informal reports from experience in California, the other similar tests by collaborators of this committee showed no increase, and more frequently even a retardation of growth on the treated plots. The cause of this behavior is not yet known, but it is probable that certain moisture and organic material in the soil delay the dissipation of the toxic principles, so as to make necessary a longer interval between treatment and planting than was used in the tests referred to.

5. In comparison with other soil fumigants known to be effective in nematode control, the D-D mixture in efficacy equals the best and surpasses them in at least the following qualities:
   a. it is lower in price, thus for the first time offering a fumigant suitable for economical large scale field use.
   b. it is less dangerous and less obnoxious in use and in storage.
   c. it is easier to apply.

6. It will be necessary through further studies to define the various conditioning factors and their interrelationship before all-inclusive recommendations for the use of this fumigant as a soil nematocide can be made. Furthermore improved applicators should be constructed.

Conclusions as to the value of the DD mixture control of soil-borne fungi

The results here reported of preliminary tests indicate that the DD mixture possesses sufficient fungicidal value to warrant further study. In some of the tests it was found effective against Fusarium wilt and certain fungi causing damping-off. Other tests gave less satisfying results and the character of the data presented suggests that a full knowledge of the conditioning factors for high efficacy may prove the present fumigant also fully effective against such fungi as Rhizoctonia solani and Sclerotium rolfsii.

Conclusions as to the value of DD mixture as a soil insecticide

1. DD shows definite promise of value in the control of wireworms in the irrigated areas of the Western States.

2. Minimum effective dosages have not yet been worked out but indications thus far are that its use may be economical in the case of valuable crops to be planted on infested soils. It is probable that considerable quantities can be used for this purpose.

3. DD probably cannot be used to eliminate wireworms in soils already planted, without severe injury to the crop.

4. In the dry soils in which it was tried in the West, seven days from the date of treatment seemed to be a sufficient period to allow the mixture to dissipate after which crops were planted without injury. Much longer periods were needed in the Georgia tests.

5. It is still doubtful whether it will prove economical to use DD against white grubs and related beetle larvae, which can be controlled by chemical treatments already known in those instances where the plants to be protected are sufficiently valuable to justify the expense.

6. DD readily killed the larvae of cotton pink bollworm in the soil, and its usefulness in the eradication of local outbreaks of this pest should be evaluated by further investigations.

7. DD, while effective against white-fringed beetle larvae, was not found to be as economical as methyl bromide, which is already in use for that purpose.

8. DD killed termites and other wood-infesting insects, but in view of its volatility there is some question as to whether it will find a place in the control measures directed against this type of insect.

9. DD has so far not been found of value against ants, mealybugs, or mosquito larvae.

Conclusions as to precautionary measures

1. As in the case of most other effective fumigants, certain precautions are necessary. Great care should be employed to avoid spilling DD on the shoes or clothing. If so spilled; the wet garment should be removed immediately to avoid injury to the wearer, and should not be worn again for at least several days, possibly longer.

2. No evidence has been found that root or other plants grown in DD-treated soil involve any hazard as human or animal food, although it would be desirable to put such plants through the series of toxicological tests customarily used in the case of new insecticides.

SECTION A: NEMATODES

The economic significance of nematode pests of plants

Contrary to the nematodes parasitizing man and animals those attacking plants are very small (mostly of a size between 0.4 and 1.0 mm). For this reason, and because of their hidden mode of life (largely under ground) they have been and still are often overlooked as limiting factors in plant growth and crop production. Certain forms like the root-knot nematode and some species of meadow nematodes are of a worldwide distribution, attacking a wide variety of hosts; others are restricted to certain regions and attack only a few hosts (sugar-beet nematode, citrus nematode, nematode causing red-ring disease of coconut palm, etc.). In the U.S.A. the root-knot nematode is one of the worst and most perplexing agricultural pests. It is widely distributed through the sandy soils of the Southern and Southwestern States and California, but occurs also as a limiting factor on certain crops (e.g. potato) as far north as the States of New York, Michigan, Idaho, Oregon, and Washington. It is the most generally distributed greenhouse pest. Accurate surveys are lacking and are difficult to make, but it is conservatively estimated that in certain regions annual crop losses caused by this nematode amount regularly to between 5 to 25%, with locational losses not infrequently running much higher with instances of complete failure. In the State of Mississippi, for example, the losses caused by this nematode in victory gardens alone in 1943 were conservatively estimated at over $2,000,000. Crop rotation is at present the most economical control method; it is based on the fact that certain crops are more resistant than others to the attacks of this nematode. Very few are immune. Furthermore, there are specialized host strains of this nematode. However, losses are only reduced, not avoided by rotations and often proper rotations are difficult to follow because many rotation crops are not pay-crops or are not adapted to a given region. Various cultural methods, sanitary measures, preventive measures (inspection service!) help to reduce or avoid losses. In some instances a hotwater treatment has proved a successful curative measure (e. g. in the case of peonies and other valuable nursery stock), but such methods are of restricted economic value. Certain chemicals have been shown effective against this pest as soil fumigants, e. g., chloropicrin, carbon bisulfide, methyl bromide, ethylene dichloride, and various mixtures of these. However, all these fumigants have their restrictions; with application costs of $50 to $400 per acre they are too expensive; some are poisonous or inflammable and therefore dangerous to store, handle, and apply. Furthermore, the methods of application are too complicated. The DD mixture, for which results of tests as to its nematocidal value are reported herein, offers several important advantages over all the previously known soil fumigants and will therefore bring about a decided progress in the control of nematode pests of plants.

. Tests on the Efficacy of the DD Mixture in Nematode Control

summarized by

G. Steiner

Introduction

Authority for Work: A request by the Agricultural Research Administration.

Cooperating Agencies:

1. Shell Development Company, Emeryville, Calif. (furnished fumigants).
2. The University of Florida Agricultural Experiment Station through G. R. Townsend at Belle Glade, Fla.
3. The Mississippi Agricultural Experiment Station, through J. A. Pinckard at State College, Miss.
4. The Texas Agricultural Experiment Station, through G. H. Godfrey at Weslaco, Texas.
5. The Georgia Coastal Plain Experiment Station at Tifton, Ga. through A. L. Taylor and C. W. McBeth of the Division of Nematology, U.S. Bureau of Plant Industry, Soils, and Agricultural Engineering.
6. The University of California Agricultural Experiment Station through G. F. MacLeod, M. A. Stewart, E. O. Essig, and Roderick Craig. (Circumstances beyond control made it impossible to obtain proper results in time for the present report from these California experiments.)
7. The Division of Nematology of the Bureau of Plant Industry, Soils, and Agricultural Engineering in Beltsville, Md., through J. R. Christie, J. H. Machmer, G. Steiner, and other staff members in cooperation with S. P. Doolittle, L. L. Harter and J. S. Caldwell of the Division of Fruit and Vegetable Crops and Diseases; F. Weiss of the Division of Mycology and Disease Survey; M. S. Anderson, M. C. Keyes, and N. R. Smith of the Division of Soil and Fertilizer Investigations; W. J. Latimer of the Division of Soil Survey; and W. J. Mead of the Division of Information.

Tests were also planned at Florence, S. C. but could not be performed because of manpower shortage (statement by W. W. Garner, head of the Division of Tobacco Investigations, the proposed collaborating agency of the Bureau of Plant Industry, Soils, and Agricultural Engineering).

Because of lateness of the season tests were not considered in regions farther north than Beltsville, Md.

Statistical analyses of the various experiments are either available or could be compiled but are thought too expensive and complicated for presentation here.

Additional information on tests with the DD mixture was received from the following investigators and has been summarized and incorporated in the present report.

G. K. Parris, Virginia Truck Experiment Station, Norfolk, Va.
A. G. Newhall, New York Agricultural Experiment Station, Cornell University, Ithaca, N. Y.
J. G. Brown, Agricultural Experiment Station, University of Arizona, Tucson, Arizona.
H. C. Young, Ohio Agricultural Experiment Station, Wooster, Ohio.
C. J. Gould, Western Washington Experiment Station, Puyallup, Wash.
E. J. Anderson, Pineapple Research Institute, Honolulu, T. H.

Plan and Prodecure of Experiments

In order to compare the results of these tests from various regions, a uniform plan and procedure were worked out by G. F. MacLeod of the Agricultural Experiment Station, University of California, and G. Steiner, Division of Nematology of the U. S. Department of Agriculture, and in the main these have been adhered to by the various cooperators. The design of the experimental plot was a standard Latin square 24 by 24 feet, subdivided into 16 equal plots as laid out in Fig. 1. The treatments consisted of injections of 10 cc of the D-D mixture at a depth of 6 inches at points 18 inches apart in staggered rows, 18 inches apart. Test plants used were Hubbard squash planted as seeds, 3 to a hill, 6 days after treatment. These seeds were planted in 4 rows, each row beginning 9" from edge, the hills 18" apart. The nematode pest mainly considered was the root-knot nematode (Heterodera marioni).

24 feet

U	T	U	T	6 feet
T	U	T	U	
U	T	U	T	
T	U	T	U	

Fig. 1
Plot Design
T = treated
U = untreated

Results

1. Tests at the Plant Industry Station, Beltsville, Md.

I. Field tests.

Results: Excellent control of the root-knot nematode.

Efficacy of the crude D-D mixture in controlling the root-knot nematode found to be 99 to 100%.

Effect of treatment on nematode infestation:

a. in reducing the number of plants infected:

Of 127 plants taken at random, one from each hill, in the treated plots, 97 were absolutely free of infection; 27 had a trace of infection; 2 had a slight infection; 1 had a moderate infection.

Of 126 plants taken at random, one from each hill, in the untreated plots, 107 had a heavy infection; 14 had a moderate infection; 2 had a light infection; 2 had a trace of infection; 1 had no infection.

From the treated plot 23.9% of all plants had an infection, but mostly very light.

From the untreated plot 99.2% were infected, mostly very heavy.

b. in reducing the degree.

On the treated plots the degree of infection was only a fraction of 1% as compared to between 99 and 100% on the untreated plots. This difference was even more pronounced if only the center plants on the plots were compared.

Effect of treatment on the squash plants:

a. on germination.

On the treated plots germination was about 5% less than on the untreated; 295 plants germinated from 384 seeds planted.

On the untreated plots 311 plants germinated from 384 seeds planted.

b. on emergence: Emergence was slower on treated plots.

August 26th, 13 days after treatment and 7 days after planting, the first seedlings appeared.

August 30th, a total of 255 plants had emerged on the treated plots, as against a total of 309 plants on the untreated.

September 9th a total of 295 plants had emerged on the treated plots as against a total of 311 plants on the untreated ones.

c. on growth, six weeks after planting.

The average length of plants from the treated plots was 36.82 inches; that from untreated plots was only 16.11 inches.

There was a noticeable border effect from the treated on to the untreated plots, the growth of the edging plants on the latter being decidedly better, a condition caused, as root examinations showed, by parasite control over the border line of treated into untreated plots.

By September 7 it could be noticed that the plants on the untreated plots were a little smaller and less vigorous than those on the treated plots.

Conditioning soil temperature: On August 13, when the fumigant was injected, the soil temperature 6 inches below the surface was 89° F.

Conditioning soil moisture: At time of treatment the soil was very dry; soil moisture varied from 6.63% on the N. W. corner to 9.11% on the S.E. corner of the plot, and at time of planting (August 19) these readings were 7.48% and 10.81%. Three days after planting the plot it was watered with a lawn sprinkler. From August 17 to October 2, 4.08 inches of precipitation were measured. More uniform growth in treated and untreated squares in the S.E. corner of the plot and a slight retardation in growth on the treated squares in this corner as compared with those in the N. W. corner are interpreted as related to a moisture factor. Similarly less pronounced wilting of plants on untreated plots. Moisture appears to be one of the main conditioning factors in determining the efficacy of the D-D mixture, a factor working in at least two directions: a. in a longer retention of certain toxic ingredients, thus retarding and injuring germination, emergence, and growth of plants; b. in softening the primary killing blow to the nematodes.

Classification of the soil on experimental plot (determined by W. J. Latimer, Division of Soil Survey):

On N. E. corner - Berwyn loam withgood moisture holding capacity, surface soil fairly deep.

On S.E. Corner - Berwyn silt loam with good supply of moisture even in dry seasons.

On remainder of plot - Berwyn sandy loam, hard pan phase; above the hard pan (15 inches) this soil gives a very shallow reservoir for storage of moisture, which is readily removed by evaporation in dry seasons. (See fig. 4)

Properties of soil (determined by M. S. Anderson and M. G. Keyes, Division of Soil and Fertilizer Investigations):

Phosphorus: low; potassium: very low; organic matter 1.37; p^H 4.7.

North

0 0 0 0 0 0 0 0 0 T 0 0 0 0 0 0	z z z z z z z z U z z z z z z z z	0 0 0 x 0 0 0 0 T 0 0 x x 0 0 0 0	z z z z z z z z z zU z z z z z z
z z z z z z z z U z z z z z z z z	x 0 0 x 0 0 T 0 0 x 0 0 x 0 0 0 x	z z z z z z z z U z z z x z z z z	x 0 x 0 0 0 T 0 0 0 0 0 0 0 0 0 0
0 x x y x 0 0 0 0 0T 0 0 0 0 0 0	z y z 0 z z z z U z z z z z z z	x x 0 x 0 0 0 x T 0 0 0 0 0 x 0 0	z z z z z z z z U z z z z z z z z
z z z z z z y U z z z z z z z z	0 0 x x 0 0 0 0 T 0 0 0 y 0 0 0 x	z z z x z z z z U z z z z z z z z	0 0 0 x y 0 x 0 T x x x 0 x 0 0 0

0 Root system examined in the laboratory. No evidence of root knot seen.

x Infection very slight, manifest by a few minute swellings, and verified as root knot in the laboratory.

y Infection light and diagnosed as such in the field.

z Infection moderate to very heavy, in most instances very heavy.

Fig. 4-

Chart showing root-knot nematode infection of squash plants on treated and untreated plots 6 weeks after planting, i.e. at end of experiment.

T - treated block

U - untreated block

Lateral Killing Range of D-D Mixture

Procedure: Small wads of heavily infected tomato roots in cheesecloth bags placed in rows on opposite side of, and at 3-inch intervals from, point of injection.

At conclusion of treatment period each lot of roots was removed from the bag and placed in a pot of sterilized soil in which cucumber was grown as an indicator plant.

Amount of injection: 10 cc.
Date of injection: August 26, 1943.
Root bags removed: September 2 (interval 7 days).
Soil temperature at time of injection: 22.3°C. (72°F.)
Soil moisture not determined (soil moisture of adjacent plot 10.81%).

Soil surface

y	y	x	0	0	0		0	0	0	x	y	y	z
18"	15"	12"	9"	6"	3"	P	3"	6"	9"	12"	15"	18"	21"

Point of Injection

Results: Efficacy as shown by indicator plants.

0 Complete kill, indicator plants not infected.

x Partial kill, indicator plants with very slight infection.

y Partial kill, indicator plants with light to moderate infection.

z Little if any effect, indicator plants heavily infected.

Complete kill to about 9 inches.

Partial kill to about 18 inches.

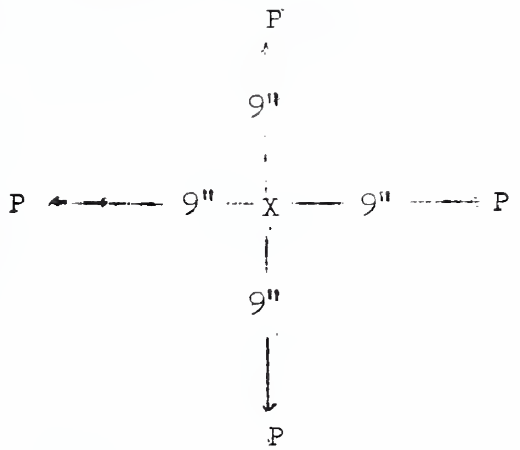
Vertical Killing Range of D-D Mixture

Procedure: Small wads of heavily infected tomato roots in cheesecloth bags were used as in the previous test. A root bag was placed just below the surface of the soil, another 9 inches deep and others at 3-inch intervals to a depth of 24 inches, the bags being in a vertical row. A square was marked on the surface of the soil of such size that it was 18 inches from corner to corner and with the uppermost root bag in the exact center. A 10 cc injection, 6 inches deep, was made at each corner of the square, each injection being 9 inches from the vertical line of root bags. The root bag 9 inches deep, therefore, was 3 inches below the points of injection and the one 24 inches deep was 18 inches below the points of injection.

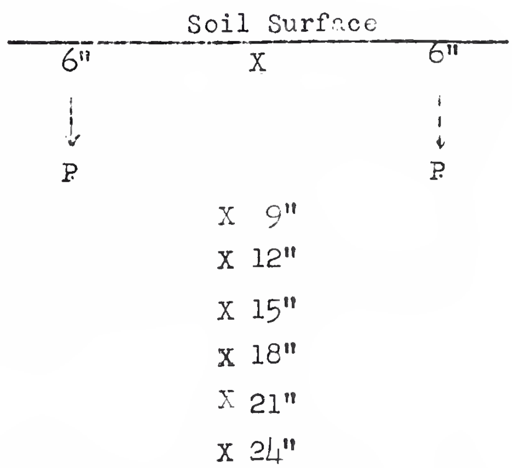
At the conclusion of the treatment period each wad of roots was tested with an indicator plant as in the previous test.

Date of injections: September 2, 1943.
Root bags removed: September 9 (interval 7 days).
Soil temperature at time of injections: 21°C. (69.8°F.).
Soil moisture not determined, probably about 10%.

Surface View



Depth View



Position of Root Bags

P Points of Injection

X Line of Root Bags

Results: No evidence of root knot could be found on any of the indicator plants. There appeared to have been a complete kill just below the surface and to a depth of 24 inches (18 inches below the points of injection).

II. Greenhouse tests.

AA. In these tests an emulsion of the D-D mixture was used containing 96% of the crude product and 4% of an emulsifier.

Procedure and plan of experiment: A bench bed 26 feet long and 4 feet wide was subdivided by cross boards into plots of 3 1/2 by 4 feet each. Plots 1, 3, 5, & 7 were untreated; 2, 4, 6, & 8 were treated. The D-D emulsion was mixed with water and applied with a sprinkling can so that 20 cc of the undiluted emulsion would cover a square foot or 280 cc each plot. The soil was infested with both the root-knot nematode and the fungus causing tomato wilt.[x]

Treatment: September 6.

Planting of plots: September 15 (9 days after treatment) tomato seedlings were planted as indicator crop for wilt as well as root knot. Between the tomato plants cucumber seeds were planted to serve as an additional indicator crop for a test for root knot control.

Results: Excellent control of the root-knot nematode.

Efficacy of control on cucumbers was between 99 and 100%, on tomatoes above 98%, these figures being based on degree of infection of the plants from treated and untreated plots.

Effect of treatment on nematodes:

a. in reducing the number of plants infected.

Of 221 cucumber plants from treated plots, 219 were not infected, 2 were only lightly infected; of 124 cucumber plants from untreated plots, 121 were heavily infected, 3 were lightly infected.

Of 57 tomato plants from treated plots, 24 were not infected, 33 were lightly infected; of 59 tomato plants from untreated plots, 59 were heavily infected.

Effect of treatment on plants:

Emergence of cucumber plants was retarded on treated plots, both cucumber and tomato plants were strongly retarded in growth, but at end of experiment had almost reached the size of those on untreated plots.

Effect of fumes on other plants in greenhouse:

None

[x] For results on tomato wilt control see page 28.

BB. WITH CRUDE D-D MIXTURE

Procedure: Two compartments (68 x 58 inches each) of a ground bed known to be heavily infested were used in this test. One compartment was treated, the other left untreated as control; 10 cc of the crude mixture were injected 6 inches deep, in holes 12 inches apart, in staggered rows 12 inches distant. Thirty-eight days after treatment 9 tomato seedlings (6 inches high) were planted in each plot; the next day Acorn squash seeds were planted between the tomato seedlings but failed to grow. Experiment terminated 64 days after treatment.

Results: Excellent control of the root-knot nematode.

Efficacy: 100%

Effect of treatment on nematodes in reducing number of plants infected:

Of 8 tomato plants on treated plot, all were free of infection.

Of 9 tomato plants on untreated plot, all were heavily infected.

Effect of fumes on other plants in greenhouse:

None.

2. Test at the Everglades Experiment Station, Belle Glade, Florida
(G.R. Townsend cooperating)

Results: No satisfactory control of the root-knot nematode.

Efficacy of the crude D-D mixture in controlling the root-knot nematode found to be only 35-40%.

Effect of treatment on nematode infestation:

a. in reducing the number of plants infected.

All but a few plants from the treated plots had galls.
All plants from the untreated plots had galls.

b. in reducing the degree of infection.

In view of the somewhat smaller root system of the plants from the treated plots, the actual control of nematodes is stated as only 35-40%.

Effect of treatment on the squash plants:

a. Germination on the treated plots was about 30% less than on the untreated.

b. Emergence was retarded by treatment.

c. Growth was also retarded; very few plants on the treated plots attained the size of those on the untreated plots by the time the experiment was terminated. The roots were found to be smaller on plants from the treated plots.

Conditioning soil temperature: At time of treatment, 91° F. at a depth of 3 inches; at time of planting, 81° F. at a depth of 3 inches.

Conditioning soil moisture: At time of treatment, 64.6%; at time of planting, 64.8%. Subsequent precipitation to end of experiment amounted to a total of 8.32 inches.

Classification of soil: Everglades peat.

Properties of soil (determined by M.S. Anderson and M.G. Keyes, Division of Soil and Fertilizer Investigations):

Sample A: Phosphorus: low; potassium: very low; organic matter: 87.1; pH: 6.8.

Sample B: Phosphorus: high; potassium: very high; organic matter: 85.2%; pH: 6.4.

3. Test at the Georgia Coastal Plain Experiment Station, Tifton, Ga.

A.L. Taylor reporting

Results: Excellent control of the root-knot nematode.

Efficacy of the crude D-D mixture in controlling the root-knot nematode found to be 100%.

Effect of treatment on nematode infestation:

a. in reducing the number of plants infected.

All plants on treated plots were free of root knot.
All plants on untreated plots were infected.

b. in reducing the degree of infection.

All plants on treated plots were free of infection.
All plants on untreated plots were heavily infected.

Effect of treatment on the squash plants:

No observable difference in growth of plants on treated and untreated plots. Growth poor on all plots due to lack of rain.

Conditioning soil temperature:

About 88° F. at depth of one foot at time of treatment.

Conditioning soil moisture:

6.1% at time of treatment.

Classification of soil:

Norfolk sandy loam.

Properties of soil (determined by M.S. Anderson and M.G. Keyes of the Div. of Soil and Fertilizer Investigations):

Phosphorus: medium; potassium: very low; organic matter: 0.96; pH: 6.2.

Remarks: Similar tests with only 5cc doses of D-D mixture also gave perfect control of root knot, while injections of 2.5cc resulted in control of better than 95%. In all these tests cantaloupes were used instead of squash as indicator plants.

4. Test at the Mississippi Agricultural Experiment Station, State College, Miss. (J.A. Pinckard reporting)

Results: Excellent control of the root-knot and meadow nematodes.

Efficacy of the crude D-D mixture in controlling the root-knot nematode and meadow nematodes found to be very high. (10 cc injected at 18 inch intervals).

Effect of treatment on nematode infestation (root knot only):

a. in reducing the number of plants infected.

The roots on the treated plots were not entirely free of galls, though nearly so. The galls on the roots from the untreated plots were far too numerous to count successfully.

b. in reducing the degree of infection.

See previous paragraph.

Effect of treatment on the squash plants:

Almost no differences in the above ground appearance of the squash plants on treated as against those on untreated plots were noted; the experiment was terminated by frost.

Conditioning soil temperature: At time of treatment, 95°F. at 6 inches depth.

Conditioning soil moisture: At time of treatment, 5.75%. A heavy irrigation followed planting and two subsequent irrigations were provided at weekly intervals. Extremely hot dry weather prevailed with no rain of consequence.

Classification of soil: Ocklocknee fine sandy loam.

Properties of soil (determined by M.S. Anderson and M.G. Keyes of the Division of Soil and Fertilizer Investigations):

Phosphorus: very high; potassium: low; organic matter: 2.56%; pH: 5.8.

Additional information:

a. Observations on control of meadow nematodes (*Pratylenchus* sp.).

The experimental plot carried a heavy infestation of meadow nematodes in addition to the root-knot nematode. The control of these meadow nematodes was so complete that the treated plots were densely covered with grasses and other weeds by the end of the experiments, while these grasses and weeds had died out on the untreated plots primarily through heavy attacks by meadow nematodes as root examinations proved. The squash roots were not attacked by meadow nematodes.

b. Observations on a treatment in a home garden with a rather heavy, cloddy soil of the clay loam type.

In this experiment the procedure followed was essentially the same as above described; however for comparison a treatment with chloropicrin (CCl_3NO_2) was also made. The latter was machine injected, 3 cc per dose, 6 inches deep, 10 inches apart. No surface cover was provided.

The results were not clear-cut. Neither chloropicrin nor the D-D mixture completely controlled root knot. Sufficient reduction in infection occurred, however, to produce normal appearing, vigorous squash plants.

5. Test at the Texas Agricultural Experiment Station Substation, Weslaco, Texas

(G.H. Godfrey reporting)

Results: Excellent control of the root-knot nematode.

Efficacy of the crude D-D mixture in controlling the root-knot nematode found to be 99 to 100%.

Effect of treatment on nematode infestation:

a. in reducing the number of plants infected.

Of 128 plants on treated plots only 25, or 19.5% were infected.

Of 128 plants from untreated plots 128, or 100%, were infected.

b. in reducing the degree of infection.

On the treated plots an average of only 1/3 gall per plant was observed.

On the untreated plots an average of 500 galls per plant was counted.

Thus the infestation was reduced to less than 1/1500 of the original population.

Effect of treatment on the squash plants:

a. Germination on treated plots was reduced.

b. Emergence on treated plots was retarded.

c. Growth on treated plots was retarded.

Six days after planting the plants on treated plots were much smaller than the controls and slightly yellowish; at end of experiment the average of plants from treated plots was 39.95 inches, that from untreated plots 50.55 inches; plants on treated plots were then as healthy in appearance and color as those from untreated plots.

Conditioning soil temperature: At time of treatment, 80°F., at time of planting, 72°F.

Conditioning soil moisture: At time of treatment, 0.8%, at time of planting, 13%. Rain and irrigation provided excellent moisture conditions during period of experiment.

Soil classification: Victoria fine sandy loam, packed rather firm below 7 inches.

Properties of soil: Not known.

6. Tests at the Virginia Truck Experiment Station, Norfolk, Va.

G.K. Parris reporting

Test AA included the following chemicals:

Crude D-D mixture.
Purified D-D mixture.
Monochlorobutenes.
Trichlorobutanes.
Chloropicrin.

Procedure: Greenhouse soil from a cucumber bed heavily infested with the root-knot nematode was transferred to an outside concrete container 6 feet wide, 2 feet deep, and 75 feet long. Each chemical was injected into 3 replicated areas of 15 square feet each, the treated areas separated by an untreated space one foot wide to prevent inter-plot diffusion of the fumigants. Injections were at the rate of 150 lbs. per acre in holes 3 to 4 inches deep at intervals of 12 inches, the rows 12 inches apart. (In the case of the D-D mixture, this amounts to about 3 cc per injection point.) After treatment the surface soil was "wetted down" and plots with chloropicrin injections were covered with a double layer of wet gunny sacking. Two weeks after treatment tomato seeds were planted. The odor of the D-D mixture was then still noticeable, that of the 3 other chemicals had disappeared, in fact the odor of the D-D mixtures was noticeable to the end of the 7 weeks growth period at which time the tomato plants were dug. Rain fell intermittently for 3 days soon after the treatment of the soil.

Results: Good control of the root-knot nematode by the purified and crude D-D mixture and by chloropicrin. No control by monochlorobutenes and trichlorobutanes.

Efficacy not exactly determined.

Table 1. Relative degree of control of *Heterodera marioni* in infested soil treated with various chemicals at the rate of 150 pounds per acre. Indicator crop was tomato.

Treatment of soil	Type of nematode attack	Mean fresh weight of tops (grams)
Untreated	Severe	58.5 ± 11.7
Monochlorobutenes	Severe	58.0
Trichlorobutanes	Severe	78.0
D-D (pure)	Slight to moderate	85.5
D-D (crude)	Slight to moderate	99.0
Chloropicrin	Slight to moderate	114.0

Test BB.

Procedure: The soil used in previous test AA was removed from its container, well mixed and replaced.[x] Using approximately 25 square feet of soil per plot the soil was treated with chloropicrin, with the purified and crude D-D mixture at the rate of about 3 1/2 cc per injection point (180 lbs. per acre) spaced as in test AA, each treatment in 3 replicates. Untreated soil served as control. As in the other treatment the soil was wetted down but in this second test the soil on the chloropicrin plots was left uncovered. Bush beans were selected as test plants, because of advanced season, and sown at 3 different dates, 11, 16, and 18 days respectively after treatment. Sash was placed over the plots 6 days after the last planting and maintained in place with appropriate regulations to outside temperature. One month after the first planting the bean plants were dug.

Results: Good control by both purified and crude D-D mixture, not so good control by chloropicrin obviously because no cover was applied after treatment to prevent the vapors from quick escape.

Efficacy: Not exactly determined.

Table 2. Relative degree of control of *Heterodera marioni* in infested soil treated with chloropicrin, with D-D (pure or crude product), or left untreated. Indicator crop was bush bean.

Treatment of soil	Type of nematode attack	Percent germination Days after treatment of soil 11	16	18
Untreated	Severe	82.5 ± 6.1	84.2 ± 4.3	82.6 ± 4.3
D-D (pure)	Slight to moderate	64.0	79.5	76.0
D-D (crude)	Slight to moderate	68.0	77.7	69.6[a]
Chloropicrin	Moderate	65.0	89.2	83.6

[a] Reduction caused by killing of plants by *Sclerotinia sclerotiorum*, not considered to be due to soil fumigant.

Effect of D-D mixture on plants:

See above table containing data on germination.

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[x] This test is here reported despite the fact that the soil used in the previous experiment was used over again, a procedure not beyond criticism.

7. Test by Agricultural Experiment Station, Cornell University, Ithaca, N.Y.

A.G. Newhall reporting

Test in greenhouse at Rochester, N.Y.

Procedure: Dosages of 1 1/2 and 2 1/2 cc of D-D mixture (crude?) injected at ? inches depth in holes 10 inches apart and rows 10 inches distant. Each treatment and check in 5 randomized replicates. Plots were watered immediately after treatment. Test plant: Summer squash, dug after 25 days. Soil: Sandy loam.

Results: Excellent control of the root-knot nematode.

Efficacy of 1 1/2 cc dosage about 95 to 96%
of 2 1/2 cc dosage about 98 to 99%

Number of galls per plant (Summer squash) 25 days after planting

Untreated plots	Plots treated with 1 1/2 cc DD	Plots treated with 2 1/2 cc DD
90.5	3.3	.4
54.0	2.4	.5
55.1	3.4	.9
46.0	2.4	1.4
51.1	.9	.7
296.7	12.4	3.9

Additional information: D-D mixture used at the rate of 7 cc per injection at 10 inch intervals was found to be very injurious to plant growth. In another test where the fumigants were used at minimum dosage rates, which failed to control the nematode, an apparent stimulating effect was observed on the growth of tomato plants in pots by the D-D mixture.

8. Observations at the Agricultural Experiment Station, University of Arizona

J. G. Brown reporting

A small quantity of the D-D mixture had been used in a test on soil heavily infested with the root-knot nematode. It was believed that the fumigant was working well, for test plants were thriving. Suddenly, however, these plants began to yellow and die; investigation disclosed that the roots of such plants were badly knotted. Obviously the fumigant had not killed the root-knot nematodes inside the large roots that were buried in the soil as an inoculum.

Conclusions as to the usefulness of the DD mixture as a Soil Fumigant for Nematode Control

1. The DD mixture, either in crude, purified, or emulsified form, properly injected or applied, proved highly effective in control of the root-knot and the meadow nematode in sandy, sandy loam, and silt loam soils of rather low moisture and low organic content.

2. The DD mixture proved only about 35 to 40% effective in control of the root-knot nematode in Everglades peat of high moisture (around 65%) and high organic (85 to 87%) content.

3. Soil moisture content above a certain level tended to retain DD ingredients toxic to plant growth without increasing the lethal effect on nematodes.

4. In these preliminary tests it was not possible to carry the plants through to maturity so late in the season, and to obtain final yield records. The field test at Beltsville showed, however, during a growth period of six weeks, a marked increase (125 percent) in plant growth on treated as compared with untreated soil. While Dr. Carter reports a similar favorable effect on growth, and this effect tends to be confirmed by informal reports from experience in California, the other similar tests by collaborators of this committee showed no increase, and more frequently even a retardation of growth on the treated plots. The cause of this behavior is not yet known, but it is probable that certain moisture and organic material in the soil delay the dissipation of the toxic principles, so as to make necessary a longer interval between treatment and planting than was used in the tests referred to.

5. In comparison with other soil fumigants known to be effective in nematode control, the DD mixture in efficacy equals the best and surpasses them in at least the following qualities:

   a. It is lower in price, thus for the first time offering a fumigant suitable for economical large-scale field use.
   b. It is less dangerous and less obnoxious in use and in storage.
   c. It is easier to apply.

6. It will be necessary through further studies to define the various conditioning factors and their interrelationship before all-inclusive recommendations for the use of this fumigant as a soil nematocide can be made. Furthermore improved applicators should be constructed.

SECTION B. FUNGI

Tests on the Efficacy of the D-D Mixture in Control of Parasitic Fungi Occurring in the Soil

S.P. Doolittle, F.S. Beecher, L.L.Harter, & W.D.Moore reporting.

Summarized by G. Steiner

1. Greenhouse test with Fusarium wilt of tomatoes (*Fusarium bulbigenum* var. *lycopersici*). S. P. Doolittle and F. S. Beecher, Beltsville, reporting.

Procedure: The soil used in this test had grown diseased plants and was provided with additional inoculum through incorporation of 20 quarts of a fungus suspension in water and of fragments of infected stems and roots. After this inoculation the soil was kept moist for 10 days at an optimum soil temperature of 80° F. by a heating cable. The bench was divided into 8 compartments of 52 x 24 inches each. At the end of 10 days each alternate compartment was treated with the D-D mixture in the form of emulsion.

Results: Excellent control of the Fusarium wilt fungus.

Efficacy of D-D mixture applied in form of emulsion (96% of crude D-D), 20 cc to square foot, diluted in water (50:50) found to be over 94%.

Effect of treatment on fungus infestation in reducing the number of plants infected after 3 weeks' exposure to the fungus.

Of 276 plants on treated plots 2 marginal ones were found infected, i.e. only 0.7%.

Of 285 plants on untreated plots 36 were found infected, i.e. 12.6%.

Effect of treatment on tomato plants: Injury observed on all tomato seedlings planted 1-3 weeks after treatment, first planting severely damaged.

Conditioning soil temperature at time of treatment: Around 80° F.

Conditioning soil moisture: Ten days before treatment with D-D mixture the inoculum (20 quarts of a fungus suspension in water and fragments of infected roots and stems) was put into the soil and the latter kept moist and at 80° F. during the full 10 days prior to treatment. After treatment the soil was heavily watered twice daily.

Classification of soil: Sandy loam.

Properties of soil: Not known.

2. Greenhouse test with the Southern blight or sclerotium rot fungus (Sclerotium rolfsii).
S. P. Doolittle and F. S. Beecher, Beltsville, reporting.

Procedure: The bench soil used in this experiment was already infested with the present fungus and contained in addition a heavy infestation of the root-knot nematode. Two days before treatment additional fungus inoculum was incorporated at two-inch levels throughout the depth (7 inches) of the soil. The soil was kept very moist for 2 days and then the treatment was made as in the previous experiment. Twelve days after treatment 10 inch tomato seedlings were planted but were badly injured and were therefore replanted 3 weeks after treatment in such a way that each section contained 15 tomato plants; these tomato plants were then interplanted with 6 rows of cucumber seeds, 12 seeds per row.

Results: Excellent control of the Sclerotium rot fungus.

Efficacy of D-D mixture applied in form of emulsion (96% of crude D-D), 20 cc to square foot, diluted with water (50:50) found to be 100%.

Effect of treatment on fungus infestation:
Cucumber
a. in reducing the number of plants infected:

Of 256 cucumber plants on the treated plots none was infected, i.e. 0%

Of 173 cucumber plants on the untreated plots 62 were infected, i.e. 35.8%, and had died 25 days after planting.

b. in increasing the number of seeds germinated:

On treated plots 256 cucumber seeds germinated while on the untreated plots this number was only 173, the difference being thought to have been caused by seed decay through Sclerotium rolfsii and other fungi.

Tomato: No infection during 5 weeks' exposure to the fungus.

Effect of treatment on tomato and cucumber plants:
Tomato seedlings (10 inches) planted 12 days after treatment exhibited severe injury; tomato seedlings planted 3 weeks after treatment still showed some injury on treated plots and retardation in growth but on termination of experiment (57 days after treatment, 36 days after planting) had almost reached the size of plants on untreated plots. Cucumber seeds planted 3 weeks after treatment germinated better on treated plots but emergence was delayed and the plants were slightly stunted.

Conditioning soil temperature at time of treatment: 65° - 70°

Conditioning soil moisture: After the inoculum had been added, i.e. two days before treatment, the soil was kept very moist; after treatment the soil was heavily watered twice daily.

Classification of soil: Clay loam.

Properties of soil: Not known.

3. Test with Rhizoctonia solani, a fungus causing seed decay and damping-off of cucumber seedlings.
S. P. Doolittle and F. S. Beecher reporting.

Procedure: A section of bench was divided into four subsections, 4 x 2 feet each. Part of the soil was removed and replaced by a 2-inch layer of soil known to be infested with the present fungus from previous tests with cucumber seedlings. The treatment of the two sections with D-D mixture was the same as tests 1 and 2. Two weeks after treatment the 4 sections were planted with cucumber seeds at the rate of 250 seeds per section.

Results: Unsatisfactory.

Efficacy of D-D mixture in form of emulsion (96% of crude D-D) 20cc to square foot, diluted in water (50:50) found to be only 39.2%.

Effect of treatment on fungus control in reducing the number of plants infected:

Of 468 plants on treated plots, 12 (or 2.56%) showed damping off 3 weeks after planting of seeds.

Of 385 plants on untreated plots, 25 (or 6.52%) showed damping off 3 weeks after planting of seeds.

Effect of treatment on the cucumber plants:

a. on germination:

Of 500 seeds planted on treated plots 468 (or 93.6%) germinated.
Of 500 seeds planted on untreated plots 383 (or 76.6%) germinated.
Treatment appeared to reduce pre-emergence damping-off.

b. on emergence:

This was retarded on treated plots.

c. on growth:

Some plants on treated plots were stunted.

Conditioning soil temperature: About 73° - 75°F.

Conditioning soil moisture: High moisture.

Classification of soil used for experiment: Sandy loam mixed with muck soil.

Properties of soil: Not known.

D. Test on control of damping-off of cabbage seedlings in Soil artificially infested with Sclerotium rolfsii.
W. D. Moore, Tifton, Georgia reporting.

Procedure: Greenhouse soil was infested with Sclerotium rolfsii by mixing infected millet seed with the soil. After treatment the soil was kept in bins and transferred to greenhouse flats after all detectable odor had disappeared. Treatments were made at dosages as follows: 1cc, 2 1/2cc, 5cc, and 10cc, respectively, to the square foot of soil. In each experiment there were 8 replicates of the treatment and of the control. One hundred cabbage seeds were planted in each flat. The soil was moist enough to insure germination and the flats were not watered during the experiment.

Results: Negative.

Efficacy: None; the untreated controls showed a better stand and less damping off than the treatments.

Effect on damping-off fungus:

On treatments of 1cc dosage	20.2% damping off
On treatments of 2 1/2cc dosage	25.5% damping off
On treatments of 5cc dosage	13.6 damping off
On treatments of 10cc dosage	15.9% damping off
On untreated control	11.1% damping off

Effect on plants:

On treatments of 1cc dosage mean stand of 63.0
On treatments of 2 1/2cc dosage mean stand of 66.8
On treatments of 5cc dosage mean stand of 74.7
On treatments of 10cc dosage mean stand of 71.1
On untreated controls mean stand of 78.6

Conditioning soil temperature: Not known.

Conditioning soil moisture: Moist enough to insure germination.

Classification of soil: Not known.

Properties of soil: Not known.

5. Test with the wilt fungus (Fusarium) of sweet potatoes.
L. L. Harter, Beltsville, Md. reporting.

Procedure: The soil in a greenhouse ground bed had been used three years for growing beans. This soil was removed to a depth of about 10 inches and replaced with new soil from the farm. The bed was then divided into 6 blocks. Sweet potato vines and roots infected with the wilt organism were worked into the soil of 3 of the blocks and allowed to rot for 13 days, when 2 of these inoculated blocks were treated with the crude D-D mixture, 20cc injected at depth of 6 inches in holes 12 inches apart in staggered rows of 12 inches distance. Eighteen days after treatment 50 sweet potato plants were set in each of the 3 inoculated blocks.

Results: Unsatisfactory control of the sweet potato wilt fungus.

Efficacy of treatment about 45%.

Effect of treatment on fungus infestation in reducing the number of infected plants:

Of 100 plants in the two treated blocks, 11(or 11%) were infected.

Of 50 plants in the single untreated block, 12 (or 24%) were infected.

Effect of treatment on sweet potato plants:

There was no retarding nor any stimulating effect observed on the plants of the treated blocks as compared with those of the untreated one.

Conditioning soil temperature: Not known.

Conditioning soil moisture: Not known.

Classification of soil: Not known.

Properties of soil: Not known.

6. Miscellaneous tests.

AA. Tests at the Ohio Agricultural Experiment Station, Wooster, Ohio. H. C. Young reporting.

These tests included the seedling disease of sugar beets, the Fusarium wilt and the Verticillium wilt of tomatoes.
In every case the results were negative.
It is concluded that the D-D mixture has only slight fungicidal effect.
No details of experiments are available.

BB. Test at the Western Washington Experiment Station, Puyallup, Washington. C. J. Gould reporting.

Preliminary laboratory tests applying the D-D mixture as a dip against the basal rot fungus of daffodils were not sufficiently promising to warrant field tests.

CC Tests at the Pineapple Research Institute, Honolulu, T. H. E. J. Anderson reporting.

"In the course of brief tests, it appeared that the D-D mixture when applied to soil under controlled conditions and in small quantities at the rate of about 200 lbs. per acre foot, was very effective against a Pythium species, probably *P. graminicolum*."

Conclusions as to the value of the D-D mixture for the control of soil-borne fungi.

The results here reported of preliminary tests indicate that the D-D mixture possesses sufficient fungicidal value to warrant further study. In some of the tests it was found effective against Fusarium wilt and certain fungi causing damping-off. Other tests gave less satisfying results but the character of the data presented suggests that a full knowledge of the conditioning factors for high efficacy may prove the present fumigant also more fully effective against such fungi as *Rhizoctonia solani* and *Sclerotium rolfsii*.

SECTION C. INSECTS

The larvae of many groups of insects, as well as some adults such as termites and ants, live in the soil. The most troublesome in farming operations are the younger stages of certain families of beetles. These grubs and wireworms feed on the roots of plants and while capable of destroying the entire crop more commonly cause a substantial reduction in yield. They may be partially controlled in many instances by following certain rotation and cultivation practices, but there is need for an inexpensive chemical treatment that would rid the soil of such pests where valuable crops are to be planted.

Wireworms

The following summary of the economic importance of wireworms and the resume of control measures has been prepared by W. H. White, In Charge, Truck Crop and Garden Insect Investigations and C. M. Packard, In Charge, Cereal and Forage Insect Investigations.

Wireworms have been known for at least 150 years as one of the important native insect pests of agriculture in the United States. They are easily recognized by their shiny, wirelike, yellow- to orange-colored bodies and by their habit of feeding only on the underground portions of plants. Many different kinds attack cultivated crops, under all conditions of climate and soil. Certain species, the Pacific Coast wireworm (Limonius canus Lec.), the sugar-beet wireworm (L. californicus (Mann.)), the western field wireworm (L. infuscatus Mots.), and the Columbia Basin wireworm (L. subauratus Lec.)), however, are especially destructive to the crops grown on the irrigated lands of the Pacific Northwest. These wet-land wireworms are native to the region; but, because of the dry soil conditions of the greater portion of the land during the practically rainless summer months, they were originally restricted to the naturally damp soils near streams and lakes. When irrigation was introduced into the drier areas, however, these wet-land wireworms began migrating to the places made more favorable by the use of water throughout the dry season. At present various species of these wireworms are found in destructive numbers on nearly all the irrigation projects, both private and governmental, in Washington, Oregon, and Idaho, as well as in northern Utah and western Montana. In addition, they are generally distributed in the wet coastal belt west of the Cascade Mountains, where they occasionally cause damage on the more intensively cultivated lands.

It is difficult to estimate the damage done by wireworms in dollars, but the loss to farmers runs into several millions annually. While no crop is known to be entirely immune to the attacks of wireworms, such vegetable crops as potatoes, corn, small grains, onions, lettuce, melons, beans, and sugar beets are particularly susceptible to injury. The average annual loss from damage to the marketable potato crop alone amounts to approximately $4,000,000 in the four States of Washington, Oregon, Idaho, and Montana. The probable total loss to truck farmers on the irrigated lands of these states exceeds $6,000,000 annually. Besides these direct financial losses from the destruction of seed and the reduction in

volume of freight to transportation companies, increased financial risks to banks and loan companies, and, finally, in extreme instances, the necessity for a complete change of farming methods in a community.

The wheat wireworm (Agriotes mancus) of the Northeastern and Middle Western States, the corn wireworms (Melanotus spp.) of the Middle Atlantic and New England States, and the Mississippi Valley, the meadow wireworms (Limonius spp.) and the corn and cotton wireworm (Horistonotus uhlerii) and the Gulf wireworm (Heteroderes laurentii) all constitute pests of agriculture in these regions and, besides, in the dry farming area regions of the Northwest, and the wet regions of the northern Middle West, the dry land wireworm (Corymbites noxius) causes annual damage. The tobacco crop in the Connecticut Valley and in the bright tobacco belt of the Carolinas is injured, particularly following transplanting of the tobacco from the seedbed to the field, by wireworms belonging to the genus Agriotes.

The vegetable crops in some areas along the Atlantic Seaboard and in New York State as far north as Maine are also subject to injury by these pests.

The control of wireworms or the reduction of crop losses from the feeding of these subterranean pests has been accomplished in many instances by crop rotation or land handling. It is beyond the realm of economic practice to treat large fields of low priced crops with chemicals for the control of these pests, therefore the matter of land handling has been resorted to as a means of preventing injury. In the irrigated lands of the Northwest and in California and in some high-producing areas of the Eastern States chemical control has been practised. This consisted of treating the soil with chemicals such as naphthalene, carbon bisulfide, or calcium cyanide. Calcium cyanide has been used with varying results, particularly in California. The practice in the use of this material is first to plant the area with low-grade seed which serves to concentrate the wireworms, as they are attracted to these sprouting seeds, and the calcium cyanide is applied directly to this seeded area. After a week or 10 days has elapsed the main crop of seed is planted. The use of carbon bisulfide has been restricted because of the difficulty in its application and also the cost of the material. Dichloroethyl ether has also been used to a limited extent, in California, on a commercial basis. More recently in Washington State naphthalene has been applied at the rate of 300 to 800 pounds per acre at the time of the plowing of the soil, with fairly good results. Naphthalene, in its crude form, is cheap enough to use on lands which are heavily infested with wireworms and which are to be planted to crops that yield a comparatively large return per acre. The crop rotation work in the irrigated lands has shown that alfalfa land is not particularly suitable for wireworm development but that some of the clovers are attractive to the wireworms as well as the lands that are planted to a crop which is tilled. Crop rotations which include alfalfa have been recommended as a means of reducing wireworm populations. Another method of control in irrigated lands consists of withholding irrigation water. This results in a reduction of the crop but at the same time the wireworms cannot withstand

the drying out of the soil. Flooding the land for a few days when the soil temperatures remain above 68° F. has also been effective in killing wireworms. However, none of these methods have proved to be effective under all conditions, the effectiveness of the artificial treatment varying apparently with the type of soil and climatic conditions.

White grubs and other beetle larvae

White grubs are among the most destructive of soil insects. They attack grasses, grains, potatoes, strawberries, nursery stock and most cultivated crops. While highly injurious, the use of soil insecticides against them is usually considered prohibitively expensive. Lead arsenate has been used extensively on lawns and golf greens to control the larvae of Japanese beetles and various other grubs. Carbon disulfide and ethylene dichloride are also useful under special conditions. The potential value of a new soil fumigant for pests of this type would depend on its comparative cost and effectiveness. In many instances it is desirable to treat the soil while the grass or crop is present. The destructive effect of DD mixture on plant life would therefore limit its usefulness in such cases.

Other insects

Brief tests as to the possibility of using DD mixture in the control of termites, ants, mealybugs and mosquito larvae are also reported.

WIREWORM TESTS

Test at the Ventura and Salinas, California, field stations of the Bureau of Entomology and Plant Quarantine.

(M. W. Stone reporting from Ventura, except as indicated)

Results: Wireworms successfully killed.

Effect on plants: No damage to plant when seed was planted 6 days after treatment.

Dosage: Mortality of 100% resulted from applications at 2.81 cc per square foot or over (about 320 pounds per acre); 80% were killed by 2.34 cc. Only 32% were killed at a depth of 12 inches by 1.25 cc per square foot in the open, although dosages as low as 0.72 cc per square foot were made effective in pots and flats.

Insects used: Sugar beet wireworms *Limonius californicus* 1/2 to 3/4 inch long.

Experiment 1: Eight-inch pots, soil temperature 42° to 74° F.; soil, sandy loam, moisture 12 to 14 percent by weight.

Undiluted crude DD emulsion per sq. ft.	Dilution	Amount of dilute emulsion applied per 8-inch pot	Time between treatment and examination	Wireworms per pot	Mortality
cc	cc per gal.	Quart	Days	Number	Per cent
0.18	0.25	1	5	55 to 59	40.0
.36	0.50	1	5	55 to 59	93.1
.54	0.75	1	5	55 to 59	98.3
.72	1.0	1	5	55 to 59	98.2
.72	1.0	1	3	54 to 80	96.7
.72	1.0	1	2	54 to 80	91.1
.72	1.0	1	1	54 to 80	66.2

Experiment 2: Cull beans planted in rows 1.5 cc of crude DD applied as emulsion diluted 1.5 cc pergallon, per foot of row. The wireworm mortality was 95% in 4 days.

Experiment 3: Field trial. Chemical injected into soil one inch at rate of 29.57 cc (one fluid ounce) at each corner of squares of varying sizes. Wireworms inserted in soil in screen cages at center of square. All wireworms were killed, 1 to 17 inches below surface, in the case of all squares of 22 inches and less. Mortality 70% for 24-inch squares. As a comparison, carbon disulfide gave 100% mortality only in those squares of 16 inches or less. Note. The dosage of DD in this instance was apparently much higher than necessary, but 22-inch intervals represented the maximum effective lateral penetration even for this dosage.

Experiment 4: Field trial. Soil temperature uncertain but believed to be between 63° and 92° F.; soil, sandy loam, moisture 14% to 16%. Cages examined 5 days after treatment. DD emulsified and sprayed on surface.

Undiluted crude DD emulsion per sq.ft.	Dilution	Amount of dilute emulsion per square foot	Depth of wireworms	Mortality
cc	cc per gal.	Quarts	Inches	Per Cent
1.25	1.00	5	8	30
			12	32
			16	0
2.81	1.25	9	4 to 16	100
3.00	1.50	8	4 to 16	100
0 (check)	0	0	4 to 16	3

Following this experiment, 6 days after treatment, lima beans, corn, peas, yams and tomatoes were planted. Within 12 days there was no difference in the size, appearance, or numbers of plants in the treated or untreated plots.

Experiment 5.: Field trial. DD mixture emulsified and applied to one-fourth acre in irrigation water. A dosage of 2.34 cc of crude DD emulsion per square foot (in a dilution 1.17 cc per gallon applied at 2.0 gallons per square foot) gave 80 percent mortality of wireworms in the top 16 inches of soil. Lima beans growing in the plot at the time "were injured." A dosage of 4.29 cc per square foot applied in 2.9 gallons of irrigation water per square foot on one-third acre killed all wireworms found.

Experiment 6.: (Report by G. F. York, Salinas, Cal.) greenhouse trial. DD mixture shaken up with water (no emulsifier) at 1.5 cc per gallon was sprinkled on 6 greenhouse flats, 3 inches deep, each of which had previously been artificially infested with 10 wireworms. Dosage was 0.75 cc of straight DD per square foot. No wireworms survived in the treated flats after 7 days except 8 which were "moribund". The germination of guayule, grass, and weed seeds was retarded for the first seven days but there was no subsequent residual injury.

WHITE-GRUB TESTS

Tests in Indiana, New Jersey, and South Carolina, at Field Stations of the Bureau of Entomology and Plant Quarantine

Results: White grubs and other beetle larvae killed at dosages 1.28 cc per square foot and over.

Effect on plants: Where palm, grape, or fern were growing in the soil at the time of treatment they were severely injured or killed; azaleas were slightly injured.

Experiment 1: A. C. Mason, R. D. Chisholm, and R. W. Cowles, Moorestown, N. J., and Washington, D. C. Japanese beetle larvae; various tests, July to September 1943. Soil dry. A crude DD mixture was emulsified, diluted, and sprayed on surface.

Amount of straight (crude) DD per square foot	Nature of treatment	Dilution	Amount of dilute emulsion per square foot	Depth of grubs	Mortality
CC		Cc per gal.	Quarts	Inches	Per Cent
4.2	Plot surface	19.0	0.89	4 to 9	100
1.28	pots	9.5	0.54	--	98
1.56	pots	19.	0.54	--	100
5.11	pots	38	0.54	--	100
0 (check)	pots	0	0	--	38

Experiment 2. A. C. Mason, R. D. Chisholm, and R. W. Cowles, Moorestown, N. J., and Washington, D. C. Japanese beetle eggs were killed in treated soil, but were not affected by 10 seconds immersion in dilute DD emulsion.

Experiment 3. P. Luginbill, Lafayette, Indiana. White grubs (Phyllophaga spp.) treated in tin ointment boxes. On September 20, 1943, larvae in soil were treated in each of six tin ointment boxes, one larva in each box, using dilute emulsions at dosages such that from .025 to .05 cc of straight DD was employed in each box. All the larvae were killed. The dosage rate may be considered as 0.77 cc per square foot, but the effectiveness was intensified by the closed nature of the container.

Experiment 4. Norman Allen, Florence, S. C. Grubworms, larvae of the green June beetle (Cotinis nitida), treated in tobacco plant beds. On October 2, 1943, DD mixture was applied to the surface of certain plots formerly used as tobacco plant beds. The soil had previously been infested artificially with 50 half-grown larvae per square yard.

As indicated in the table below, the dosages were very high. All larvae in all tests were killed or moribund except two that were still alive and active two days after treatment.

Amount of straight DD per square foot	Dilution	Amount of dilute emulsion per square foot	Depth of grubs	Mortality
cc	cc per gal.	Quarts	Inches	Per cent
42	189	.39	5 to 6	100
84	379	.89	5 to 6	100
168	757	.89	5 to 6	100
47	189	1.00	5 to 6	89*

*The last test was on October 12; 3 of the larvae counted here as dead were only "moribund" at the time of examination on October 14.

PINK BOLLWORM TESTS

Tests at Brownsville, Tex., field station of
Bureau of Entomology and Plant Quarantine

(Reported by L. C. Fife, A. J. Chapman, and Ivan Shiller)

Results: All pink bollworm larvae used in the experiment were killed by DD mixture.

Dosages: 4.44 cc per square foot throughout. Presumably smaller dosages will be adequate to kill this insect.

Insects used: Cotton pink bollworm larvae (*Pectinophora gossypiella*); both long-cycle and short-cycle forms.

Experiment 1: September 25 to 28, 1943. Laboratory trial. Layer of infested cotton bolls placed in box (16 by 16 by 13 inches) covered with 6 inches of soil. 7.86 cc of DD mixture injected undiluted six inches deep in center of box; dosage 4.4 cc per square foot. Larvae counted at end of experiment 3 days later and proved to number 46 short-cycle, all dead.

Experiment 2: Same dates. Field trial. Layer of infested cotton bolls (14 pounds) spread out over area of 6 by 3 feet and covered with 6 inches of soil. 10 cc of undiluted DD were injected into each of several holes 18 inches apart, giving a dosage of 4.44 cc per square foot. At the end of the experiment 3 days after treatment, half the bolls were examined and 244 dead long-cycle larvae found. Larvae were killed at least 9 inches from the point of application. The black sandy loam soil was practically saturated with heavy rains throughout the experiment.

TESTS ON MISCELLANEOUS INSECTS

Tests at Gulfport, Miss., field station of the
Bureau of Entomology and Plant Quarantine

(Stephen S. Easter reporting)

Results: White-fringed beetle larvae killed by the use of large quantities, but DD mixture was not found as effective or economical as methyl bromide.

Dosages: Complete mortality did not result in the open even from 24 cc per square foot. When the area was covered with paper, 12 cc per square foot killed all the beetles.

Insects used: White-fringed beetle larvae (*Pantomorus peregrinus*); natural infestation.

Experimental tests: Coarse sandy loam; soil temperature 70°-75° F.; rain fell but soil was not excessively wet.

Material	Quantity per square foot	Cover	Mortality
	cc		Per Cent
DD	3.0	None	69
DD	3.0	Paper	50
DD	6.0	None	77
DD	6.0	Paper	57 - 67
DD	5.3	Paper	56
DD	12.0	None	71
DD	12.0	Paper	100
DD	24.0	None	94
DD	24.0	Paper	100
Methyl bromide	1.13 to 2.37	Paper	100

Miscellaneous tests by employees of the Bureau of Entomology and Plant Quarantine

Experiment 1: F. F. Bondy and C. R. Rainwater, Florence, S.C. DD mixture shaken up with water (no emulsifier) applied at the rates of 1.25 cc and 7.6 cc of DD respectively per linear foot of soybean (light sandy soil) row failed to kill mealybugs and ants. (However, at Beltsville, Md., "one ant-infested 2 by 4 stake was treated with 10 cc of DD mixture with apparently complete control" - L. W. Orr.)

Experiment 2: C. M. Gjullin, Portland, Ore. DD mixture added (3%) to diesel oil and applied to the surface of the water in enameled pans only resulted in killing 4% to 16% of the mosquito larvae present, as compared to 61% mortality from 3% Nopco 1216 in diesel oil in a simultaneous comparable test.

Experiment 3: R. T. Cotton, Manhattan, Kans. Crude DD mixture at 23.59 mg. per liter killed all the rice weevils (Sitophilus oryzae) in wheat, and at 70.79 mg per liter (6 lb. per 1000 bushel) killed all the flour beetles (Tribolium castaneum) in wheat. It, however, gave such a strong odor to the wheat as presumably to cause it to grade "sample grade."

Experiment 4: Beltsville, Md. DD mixture injected 6 inches deep into the soil around, and 4 inches away from, infested posts at the rate of 20 cc and 40 cc per post killed all the termites; at 10 cc per post the termites were killed except in one instance. Within 12 inches below the surface most weevil and borer larvae were also killed but those in that part of the post deeper than 12 inches mostly survived. The mixture's usefulness for this purpose may be limited by its volatility, causing the effectiveness to be only temporary.

Conclusions as to the value of DD mixture as a soil insecticide

1. DD shows definite promise of value in the control of wireworms in the irrigated areas of the Western States.

2. Minimum effective dosages have not yet been worked out but indications thus far are that its use may be economical in the case of valuable crops to be planted on infested soils. It is probable that considerable quantities can be used for this purpose.

3. DD probably can not be used to eliminate wireworms in soils already planted, without severe injury to the crop.

4. In the dry soils in which it was tried in the West, seven days from the date of treatment seemed to be a sufficient period to allow the mixture to dissipate after which crops were planted without injury. Much longer periods were needed in the Georgia tests.

5. It is still doubtful whether it will prove economical to use DD against whitegrubs and related beetle larvae, which can be controlled by chemical treatments already known in those instances where the plants to be protected are sufficiently valuable to justify the expense.

6. DD readily killed the larvae of cotton pink bollworm in the soil, and its usefulness in the eradication of local outbreaks of this pest should be evaluated by further investigations.

7. DD, while effective against white-fringed beetle larvae, was not found to be as economical as methyl bromide, which is already in use for that purpose.

8. DD killed termites and other wood-infesting insects, but in view of its volatility there is some question as to whether it will find a place in the control measures directed against this type of insect.

9. DD has so far not been found of value against ants, mealy bugs, or mosquito larvae.

SECTION D: HERBICIDAL EFFECT ON PLANTS AND MISCELLANEOUS ORGANISMS

Tests at Yakima, Wash., field station of
Bureau of Entomology and Plant Quarantine

(Report by E. J. Newcomer)

Results: Whether DD mixture is an effective herbicide for killing pear stumps is still uncertain.

Nature of Experiment: September 11, 1943. "We made tests all the way from 4 ounces to 64 ounces per stump, dividing each dosage into four equal parts put into shallow holes dug at equal distances around the stumps. These holes were placed within a foot of the stump. We also made two tests using 8 ounces and 16 ounces, each divided into 8 doses put into holes 3 feet from the stump. Today, 5 days later, there is not yet any apparent effect from the treatment except that on the stump treated with 64 ounces some of the sprouts show discoloration of the inner bark. This indicates that the material will probably affect the growth but that the effect is rather slow."

By September 30, from one-sixth to one-half of the sprouts on the stumps treated with from 4 to 32 ounces were dead or dying. The stump treated with 64 ounces appeared entirely dead.

Laboratory Tests on the Efficacy of the DD Mixture
for the Partial Sterilization of Soil

Prepared by Nathan R. Smith

The DD mixture at the rates of 200 and 400 pounds per acre was added to Sassafras sandy loam that was nearly air dry, moist, and very wet. The soil was placed in large wide-mouthed flasks, the DD mixture placed at the center near the bottom, the flask stoppered and kept at room temperature. After 2 days, the soil was poured out into a thin layer to allow the disinfectant to evaporate and analyses made the next day for fungi, actinomycęs, bacteria, and protozoa.

In the moist series, the DD mixture at the 400 pound rate reduced the fungi from about 200,000 per gram of soil to less than 200 per gram; the actinomyces from over 3 millions to 1 million; the bacteria, from 27 millions to 3.5 millions; and the protozoa from 300 to none. With the 200-pound rate of application of the disinfectant less reduction took place in the numbers of fungi, actinomyces and bacteria, but the protozoa were all killed. In the dry soil, similar results were obtained but in the wet soil much less reduction in the numbers of the microorganisms took place and all the protozoa were not killed. The odor of the disinfectant persisted in the soil for several days in spite of the good aeration it received before and after the analyses.

These preliminary results indicate that the DD mixture will partially sterilize soil, that the protozoa are wiped out by the recommended dosage, the fungi greatly reduced, the actinomyces and bacteria considerably reduced, and that too much moisture interferes with its efficiency. It appears to be slightly less effective on the general soil population than chloropicrin which was tested under similar conditions a few years ago.

SECTION E: PRECAUTIONS TO BE OBSERVED

1. Toxicity to plants:

(a) In addition to the notes on this subject in connection with the various tests on nematodes and insects, P. M. Gilmer (BE&PQ) reports a series of special tests at Tifton, Ga., that indicate persistent toxicity to plant growth in certain soils, far beyond the 7 days apparently adequate elsewhere for dissipation of the effect of DD mixture in the soil. His report is as follows:

"Two sets of experimental plats were laid out, plats being approximately 16 feet square and arranged in a series of Latin squares. These squares carried the following treatments:

"First Series - check, 2, 4, and 8 cc of DD mixture introduced every 18 inches.

"Second Series - check, 1, 2, and 4 cc of DD mixture introduced every 14 inches.

"This last set gives an 8-inch circle for each dosage, since the centers of introduction were laid in the corners of a 14-inch equilateral triangle. The last series has been in the ground only a few weeks time, the first series has been in now approximately three months.

"The first series was planted in cow peas, the last series was planted to cantaloups. It was necessary to replant the first series some three times and in none of the treated plats has a really satisfactory stand been obtained. With the heavier dosages many of the early plantings failed to show a seedling emergence at all and in the later plantings where seedlings have emerged they have, in general, been badly damaged, stunted, and in many cases have died shortly after emergence.

"Digging into the soil on these plats shows the chemical still to be present in sufficient amounts to be readily detected by smell at depths of some four to eight inches. With the second series, where lighter dosages were used at somewhat smaller intervals, there has been some emergence of seedlings. Since conditions have been very poor for growth of any type of plants because of exceedingly dry weather, these plats do not apparently show particular difference in stands between checks and treated plats. None of the stands are at all satisfactory. Emergence has been very small and the plants show a very slightly developed root system at the present time. It is probable that these plants have not yet developed a sufficient root to reach the layers of DD mixture which show here, as in the first series, quantities sufficient at some four to eight inches deep to be readily detected by odor.

"Weed growth and grass growth on both of these series has also been exceedingly poor, so it is quite apparent that the soil has been made toxic for all plant life and in the first series has remained so for a period of approximately three months."

(b) G. T. York, Salinas, Cal., reports that grass and weed seeds were not killed but their germination was delayed so that 7 days after treatment 99 grasses and 213 weeds had sprouted on the 6 treated flats as compared with 456 grasses and 887 weeds on the flats that received only water.

In another test, flats treated with DD mixture, however, showed after 16 days, more grasses (673) than the untreated flats (213), indicating that the mixture had lost its plant toxicity during the second week.

2. Toxicity to the Operator

It is apparent that spilling DD mixture on the clothes or shoes is likely to result in skin irritation, a burning sensation, and blistering.

F. F. Bondy and C. F. Rainwater, Florence, S. C., report:

"A word of caution should be made concerning the effect of this material on the person who mixes or applies it. In the second test mentioned above, where the material was used as a spray, the person applying it got his shoes pretty wet from the spray. In a very few minutes there were burning sensations over the entire top of the feet. This was soon painful and the operator had to take off his shoes and socks and dry them out thoroughly. The feet were in a reddened condition for a couple of days but apparently no serious injury resulted."

"Also, while shaking the sprayer in order to get the material in solution, some of it spilled and the tank was wet when the operator strapped it on his back. In a very short time there was rather intense burning on the back of the operator where this had soaked through his shirt."

Dr. G. F. MacLeod, Berkeley, Cal., reports:

"DD mixture was spilled on the outside toe of a heavy field boot. After two hours exposure to hot sun in the open air, the boot was put on and in less than one minute injury occurred to the large toe. The boot was immediately removed. Two blisters about the size of a quarter developed within eight hours. These blisters were protected for ten days. During that period, the boots were worn again, the blisters broke, and within six hours pronounced swelling, pain, and high erythema developed. This continued for a period of two weeks, and was still evident to a much less degree nine weeks later. There is some question as to whether or not this injury was entirely due to the chemical, since complications in the form of infection also set in.

"It seems obvious, however, that if air is occluded, burning by DD mixture will occur within a matter of seconds. If skin has been broken, the seriousness of this burn will be greatly increased. It is therefore advisable that extreme caution be used in handling large amounts of the material."

<u>Conclusions as to precautionary measures.</u>

1. As in the case of most other effective fumigants, certain precautionary measures are necessary. Great care should be employed to avoid spilling DD on the shoes or clothing. If so spilled, the wet garment should be removed immediately to avoid injury to the wearer, and should not be worn again for at least several days, possibly longer.

No evidence has been found that root or other plants grown in DD-treated soil involve any hazard as human or animal food, although it would be desirable to put such plants through the series of toxicological tests customarily used in the case of new insecticides.